# NON-CONTACT ULTRASONIC WAVEFORMS IN METALS USING LASER GENERATION AND INTERFEROMETRIC DETECTION

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## Abstract

A range of ultrasonic waveforms have been generated in an aluminum plate by a Q-switched Nd: YAG laser. Displacements on the far side of the plate were detected on-epicentre by an interferometer with a resolution of 0.2 Å and a bandwidth of 40 MHz. At optical power densities below the ablation threshold, the thermoelastic waveform was observed without signal averaging. At increased generating power densities the waveform was seen to be modified. In all cases, good agreement was seen with predictions of wave propagation theory. Studies were also undertaken for generation at modified surfaces.

## Introduction

The use of pulsed lasers for ultrasonic generation in metals is now an established technique [1]. The generation mechanisms have been investigated by comparison to elastic wave propagation theory [2], and it has been shown that in the absence of surface damage the primary mechanism is thermoelastic expansion. At higher power densities and at treated surfaces, a range of source characteristics may be produced by laser irradiation, and these have been the study of experimental investigations [3-5].

In other work, detection of displacements at metal surfaces has been achieved using laser interferometers. The differential type, although very sensitive, is useful for only a narrow band of frequencies [6]; other designs have been reported, however, which are capable of detecting ultrasonic displacements at metal surfaces with a reasonable sensitivity and bandwidth [7-9]. The resolution of these devices is improved by the use of a piezoelectric feedback mechanism to reduce low-frequency noise.

In this paper, experiments will be described which combine laser generation and interferometric detection of ultrasonic pulses in metals. This would seem to be the first such work to include a set of waveforms taken under thermoelastic generation conditions i.e. in the absence of surface damage or prior treatment, although other workers have used higher power densities [9-11] to detect flaws.

## Apparatus

A schematic diagram of the apparatus is shown in Fig. 1. Single pulses from a Q-switched Nd:YAG laser, operating at 1.06 μm in the near infra-red, were incident upon an 10.1 mm thick aluminum plate. Each laser pulse had a half-width duration of 15 nS and an energy of 0.86J. The resultant ultrasonic transients propagated through the thickness of the plate, and were detected at the far surface by the interferometer whose beam was coaxial with that of the Nd:YAG. Detection thus occurred on-epicentre. The optical power density at the region of generation was insufficient to cause surface damage when an unfocused Nd:YAG beam was used; however, metallic ablation could be caused to occur by focusing.

The interferometer was of the Michelson type, with a sensitivity of the order of 0.2 Å. A 5mW HeNe laser was used, selected for its high signal to noise ratio ($10^4$ over 50 MHz), and the unfocused beam directed towards both the sample and the reference mirror using a beam splitter. The reference mirror was mounted on a PZT piezoelectric tube. The low frequency part of the detected signal, arising from undesirable mechanical vibrations, was fed back to the PZT tube via a high voltage amplifier, thus stabalizing the interferometer; the high frequency part of the signal containing the desired information was captured on a transient waveform recorder, and could be transferred to a computer for display and subsequent analysis. Noise on the detected signal was reduced by polishing the surface of detection, and

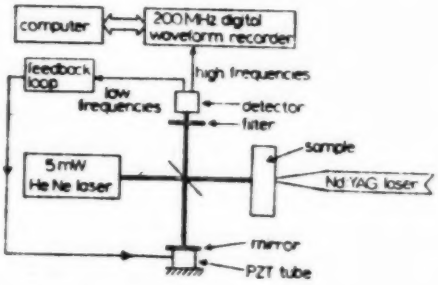


Fig. 1 Schematic diagram of apparatus

by using an interference filter to allow only 6328 Å He Ne light to enter the detector. Note that the resultant sensitivity was sufficient to allow waveforms to be captured without the need for subsequent signal processing.

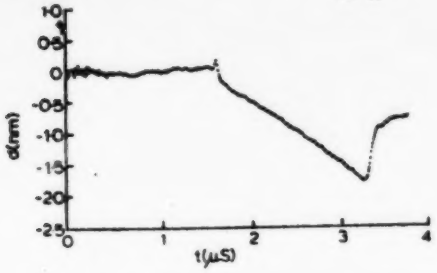


Fig. 2 Experimental thermoelastic waveform detected by interferometer.

## Results

Consider first the waveform produced at incident power densities below the ablation threshold, where generation occurs by the thermoelastic mechanism. The detected waveform is presented in Fig. 2. The longitudinal arrival at ∿ 1.6 μs was a small monopolar pulse followed by a depression of the surface. The shear wave was detected as a single step-like elevation. Note that the interferometer was sensitive to displacements normal to the aluminum surface, and this thermoelastic waveform agrees well with that detected by capacitance transducers [2].

Focusing the Nd:YAG laser caused metallic ablation and plasma formation to occur. Waveforms detected at successively higher power densities are presented in Figs. 3(a)-(c). The shear arrival tended to a change in slope at high power densities, whereas the longitudinal arrival was initially pulse-like but then tended towards a single step.

Applying surface coatings allowed longitudinal generation efficiencies to increase. Two examples are shown in Fig. 4. In Fig. 4(a), a thin oil layer was present, the detected waveform exhibiting a prominent longitudinal pulse but only a small shear step. The width at half height of the longitudinal pulse was ∿ 72nS. Transparent adhesive tape led to the waveform of Fig. 4(b). In this case a dipolar longitudinal pulse was observed. Note that in both waveforms of Fig. 4, no damage occurred to the aluminum surface.

## Discussion and Conclusions

The detected waveforms are in good agreement with those reported in previous work involving laser generation [2]. They are also in agreement with the predictions of wave propagation theory, and two relevant theoretical waveforms are

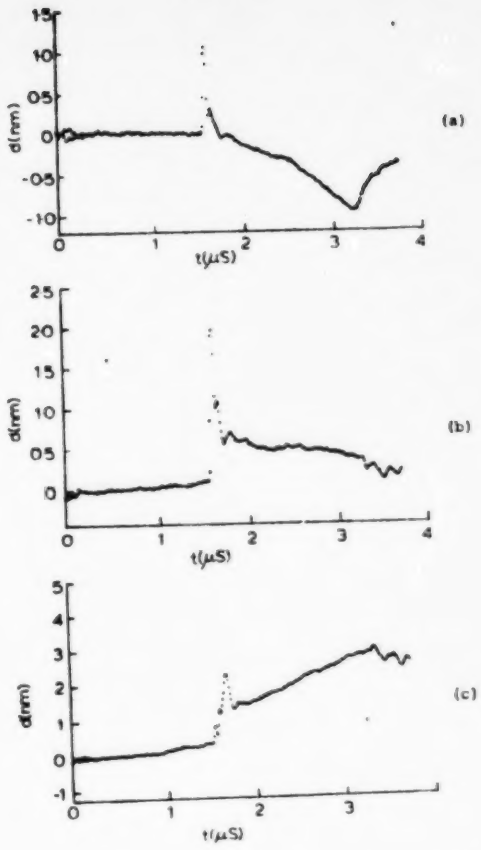


Fig. 3 Waveforms detected by the interferometer at increasing Nd:YAG power densities, above the ablation threshold.

presented for comparison in Fig. 5. Fig. 5(a) shows the epicentral displacement due to a thermoelastic source, modelled as a step-like change in volume of the material. The source is assumed to have a small but finite depth into the solid due to thermal diffusion. Good agreement is seen with the experimental thermoelastic waveform of Fig. 2. Fig. 5(b) shows the theoretical waveform for a single force normal to the surface, but with a δ-function time dependence. A force of 33N was found to produce good agreement to the experimental waveform resulting from an oil layer on the surface, presented earlier in Fig. 4(a). Normal forces arise from momentum transfer from evaporating oil, modifying the source characteristics. The waveform produced in the presence of adhesive

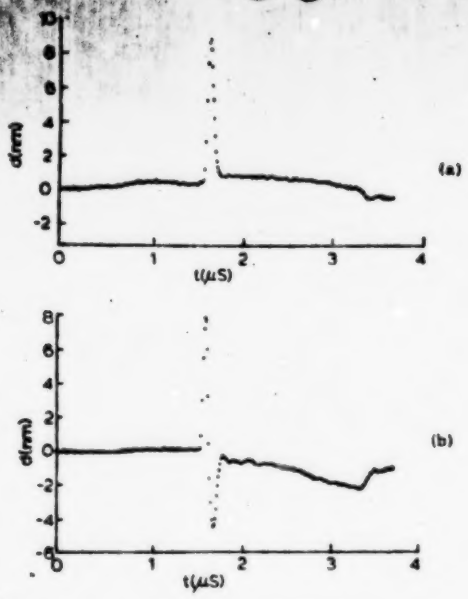


Fig. 4 Laser generated waveforms at modified surfaces, detected by interferometer (a) thin oil layer, (b) transparent adhesive tape.

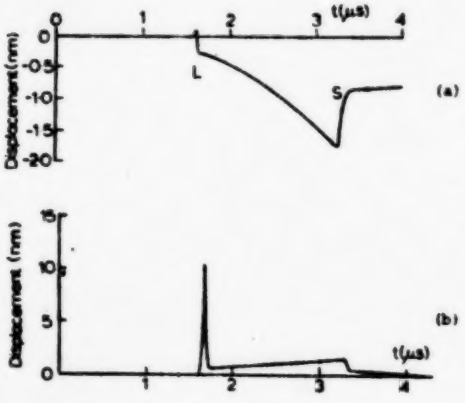


Fig. 5 Theoretical waveforms assuming (a) thermoelastic generation and (b) a δ-function normal force.

tape (Fig. 4(b)) is more complicated in that surface constraint may be a factor.

The waveforms produced under conditions of material ablation, Figs. 3(a)-(c), are a result of normal forces due to metallic ablation and other forces due to thermoelastic expansion. If these two factors are included in a theoretical analysis in appropriate proportions, then good agreement between experimental and theoretical waveforms can be demonstrated [2].

The waveforms described, detected by a sensitive Michelson interferometer, demonstrate clearly that dual laser systems are a flexible means for the study of material properties over a wide bandwidth. This may be achieved without surface damage, by using the thermoelastic generation mechanism. It is envisaged by the authors that this demonstration of the possibility of using interferometric detection and laser generation together in one system will lead to a wide range of possible applications.

## References

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